DEVELOPMENT UPDATE OF THE LECR4 ION SOURCE – DRAGON AT IMP*

W. Lu, D.Z. Xie, X.Z. Zhang, L.T. Sun, H. Wang, B.H. Ma and H.W. Zhao
IMP, Lanzhou 730000, China
B. Xiong and L. Ruan, IEE, Beijing 100190, China

[1] Also of the Graduate School of Chinese Academy of Sciences, Beijing 100049, P. R. China
[2] Visiting Scientist

Abstract

A room temperature ECR ion source, LECR4-DRAGON to operate at 18 GHz, is under development for the SSC-LINAC project at IMP. In comparison to other room temperature ECRISs, a unique feature of the LECR4-DRAGON is its plasma chamber of ID 126 mm that is the biggest chamber for a room temperature ECRIS and the same as the superconducting ECR ion source SECRAL. Because of the project funding agency requires study a different magnet cooling scheme, solid quadrate copper coils cooled by medium evaporation at about 50 ^{0}C are to be used to produce a maximum axial magnetic field of about 2.5 T at injection and 1.4 T at the extraction, which are similar to SECRAL operating at 18 GHz. Furthermore, a large bore non-Halbach permanent sextupole with staggered structure has been under fabrication which can produce a radial magnetic field reaching 1.5 T at the plasma chamber wall for operation at 18 GHz. The progress updates and discussions of this ion source will be presented.

INTRODUCTION

The LECR3 source, a room temperature ECRIS [1], is operating at IMP since 2003 and it has been delivering the most of light ion beams for the SSC cyclotron and CSR, whereas the SECRAL [2] ECR ion source has been mainly providing the highly charged heavy ion beams. To meet the demands of intense medium charge state heavy-ion beams, a research program, collaborating with IEE- Beijing, had been started two years ago. The goal of this program is to produce intense medium charge state heavy-ion beams with a room temperature ECR ion source, meanwhile testing an evaporative cooling technology [3] for potential applications to accelerator magnets. In comparison to a superconducting ECR ion source, a room temperature ECR ion source has the advantages of lower cost and easier operation but with lower performance due to the limitations on the magnetic field and ac power consumption. To date, all the room temperature ECR ion sources are built with a small plasma chamber of inner diameter less or equal to 80 mm producing a radial field of about 1.2 to 2.0 T [4]. The small plasma chambers are not optimal as evidenced by some outstanding SC ECRISs [2, 5] at about the same field profile with larger plasma chambers (ID > 120 mm). Thus a larger bore sextupole magnet has been chosen for the LECR4-DRAGON with its axial magnetic field modelling the SECRAL field profile operating at 18 GHz: 2.5 T at the injection and 1.3 T at the extraction region with a radial field of 1.4 T at the plasma chamber walls. The unique feature of LECR4-DARGON is that the solenoid magnet coils are fully immersed in and cooled with a 47.7 ^{0}C evaporative medium. Figure 1 shows the mechanical layout of the LECR4-DRAGON while Fig. 2 showing the computed axial magnetic field profile.

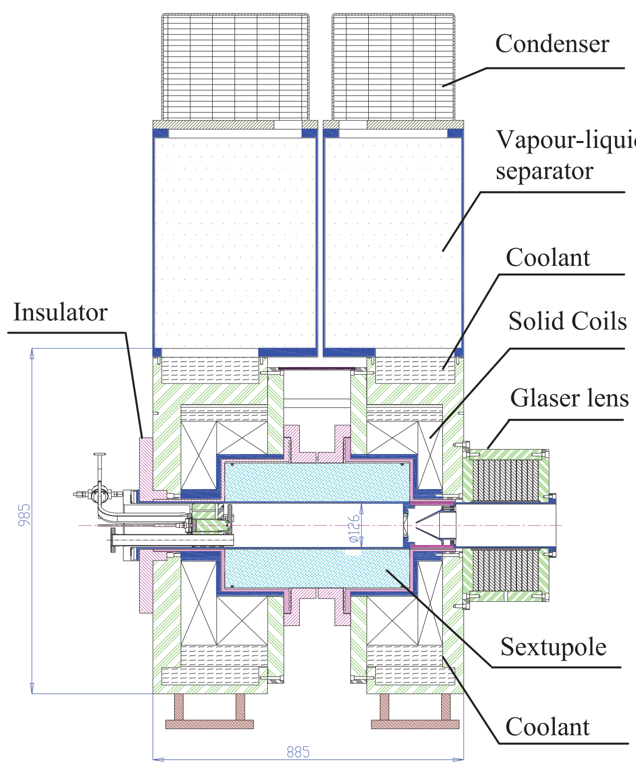

Figure 1: A schematic cross-section view of the LECR4-DRAGON. No mechanical pumping at the injection side for simplicity but may be added in the future.

Evaporative Medium Cooled Solenoid and Prototype Experiments

Institute of Electrical Engineering of Chinese Academy of Sciences (IEE) has been researching the evaporative

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cooling since 1958 [3]. Based on its structure, there are three kinds of evaporative cooling schemes in the application to the large electrical equipment: pipe inner cooling, immersion cooling and mixed cooling. Through careful theoretical analyses and experimental evaluations, the immersion scheme has been chosen for cooling the LECR4-DRAGON solenoid magnets. Figure 3 shows a schematic layout of this cooling system consisting of two condensers, liquid transport pipes, immersion tank, gas-out tubes, etc. When the coils are excited, the boil-off medium vapour will carry away the heat by a phase transition with good latent heat absorption, just like the liquid helium cooling the superconducting magnet. The vapour in the immersion tank goes up into the condenser and gets liquefied there then flows back-down to the immersion tank. To date, a prototype of solenoid coil and condenser shown in Figure 3 have been built and tested. In order to increase heat transmit efficiency and simplify ECR ion source structure as well, an integrated structure has been fabricated and tested [6]. Using coolant with a boiling temperature of 47.7 ^{0}C, the testing has achieved excitation current up to 300A that is equivalent to a current density: 12.05 A/mm^2, slightly higher than using normal hollow copper conductor with pressurized water cooling at IMP. The experimental result is shown in Table 1 that shows the maximum temperature of copper coils reaching 77 ^{0}C after 3 hours of continuous operation. This maximum temperature is about 43% of its temperature limit (180 ^{0}C- depending up on the conducting insulation grade). At the stated excitations, the maximum temperature at the permanent sextupole location is 52 ^{0}C, that is about 43% of N48SH's maximum working temperature of 120 ^{0}C.

Table 1: The Experimental Results of Prototype Solenoid Coils (2012)

Measure position	Exciting current (A)	Average Temp. (^{0}C)	Maximum Temp. (^{0}C)
Coil1conducting wire surface	303.5	70	74
Coil2 conducting wire surface	300.2	70.5	77
Permanent magnet location	-	49.5	52

Large Bore Sextupole and Force Analysis

In general a room temperature ECR ion source uses a permanent sextupole to produce the needed radial field. Most of the existing conventional ECR ion sources use a Halbach-structure sextupole that is constructed with M equal-size sections in which the easy-axis rotating (N-1)∏ /M from the section to the next [7]. Because of the superimposing magnetic fields, the Halbach structure has six potential de-magnetization regions when the field can approach dangerous de-magnetization strength. In addition, the fabrication of such a Halbach sextupole magnet requires very complex magnet-block cutting and assembling tools, especially for larger bore permanent sextupoles. To simplify the fabrications, a large bore non-Halbach-structure sextupole is used for the LECR4-DRAGON at a price of about 2% lower radial field at plasma chamber walls. The inner diameter of LECR4-DRAGON sextupole bore is 134.5 mm which is large enough to support a double-layer water-cooled plasma chamber of inner diameter of 126 mm. This large bore sextupole is made of N48SH permanent magnet blocks for its higher working temperature and possibly more resistant to the permanent magnet deteriorations with age. Figure 4 shows the cross section of the sextupole magnet and force analysis of one-sixth sextupole segment. Calculations show the maximum attractive force is up to 13000 N after assembling.

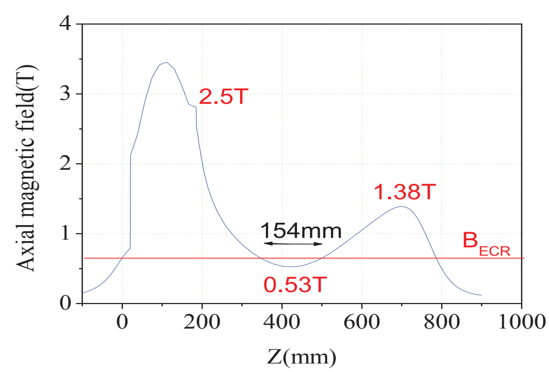

Figure 2: The axial field profile of DRAGON that is similar to the SECRAL operation at 18 GHz. With an iron plug field booster the maximum axial field reaches 2.5 T at the surface of the bias probe in the injection.

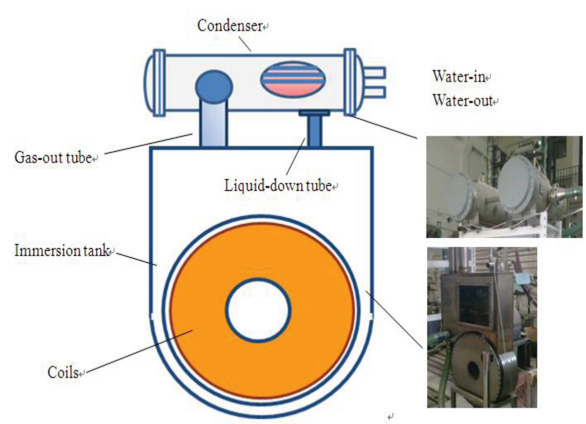

Figure 3: Schematic layout of evaporative cooling system for LECR4-DRAGON.

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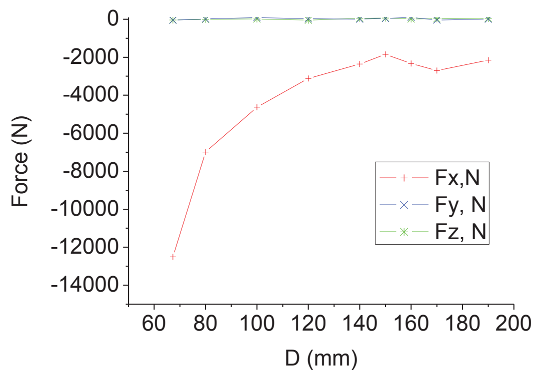

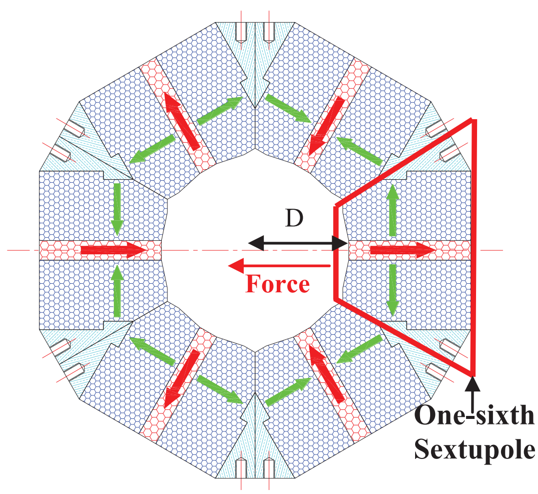

Figure 4: The layout of LECR4-DRAGON ECR ion source sextupole magnet and force analysis of one-sixth sextupole magnet.

High Voltage Beam Extraction

The beam transport line of LECR4-DRAGON is based on the one at the SECRAL beam line. It is designed to be able to transport 10-15 emA intense heavy ion beams with high efficiency and sufficient resolution. A Glazer lens and a 90^0 analyzing magnet have been chosen while the SECRAL beam line using an 110^0 analyzing magnet for slightly higher resolution. A turbo molecular pump is directly attached to the extraction box between the source and the Glazer lens to enhance the pump speed to reach higher vacuum. Pumping in the injection side is omitted for simplicity but could be added depending on the performance development. Slits and Faraday-cup are installed at the waist of extraction ion beams. LECR4-DRAGON will be insulated with 7 mm thick material hoping to achieve higher extraction voltage up to 50 kV. For simplicity a two-electrode extraction system is considered for the initial commissioning but three- and four-electrode will be explored later on. Figure 5 shows the layout of LECR4-DRAGON ECR ion source with its initial extraction system and the beam transport line.

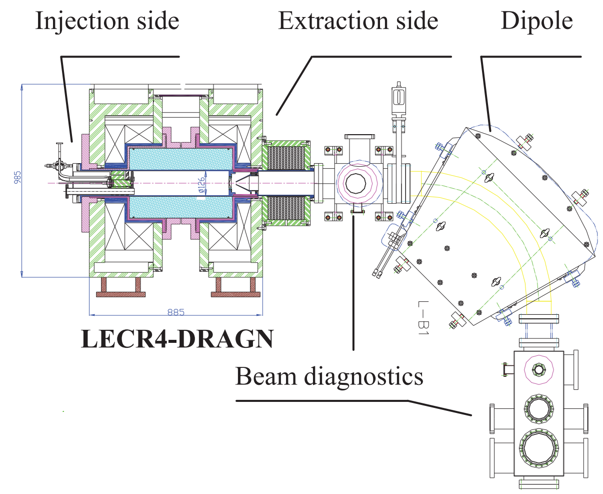

Figure 5: Layout of LECR4-DARGON ECR ion source and its beam transport line.

DISCUSSIONS AND CONCLUSIONS

The design and development of a large bore sextupole room temperature ECR ion source for the production of medium charge state heavy ion beams has been presented. The prototype of solenoid coils and the cooling condenser have been tested with satisfactory results. In order to support a large plasma chamber, a large bore non-Halbach-structure sextupole has been designed and fabrication is underway. Based on the progress, the detailed engineering design and component fabrication are underway.

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